Status of GEMS Calibration

Myoung-Hwan Ahn[1], Mina Kang[1], MiJin Eo[1], Xiong Liu[2], David Flittner[3], Dai ho Ko[4], Jhoon Kim[5]

[1]Department of Climate & Energy Systems Engineering, Ewha Womans University
[2]Harvard–Smithsonian Center for Astrophysics, Cambridge, MA, USA
[3]NASA Langley Research Center, Hampton, VA, USA
[4]Korea Aerospace Research Institute
[5]Department of atmospheric science, Yonsei University

이화여자대학교
EWHA WOMANS UNIVERSITY

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Contents

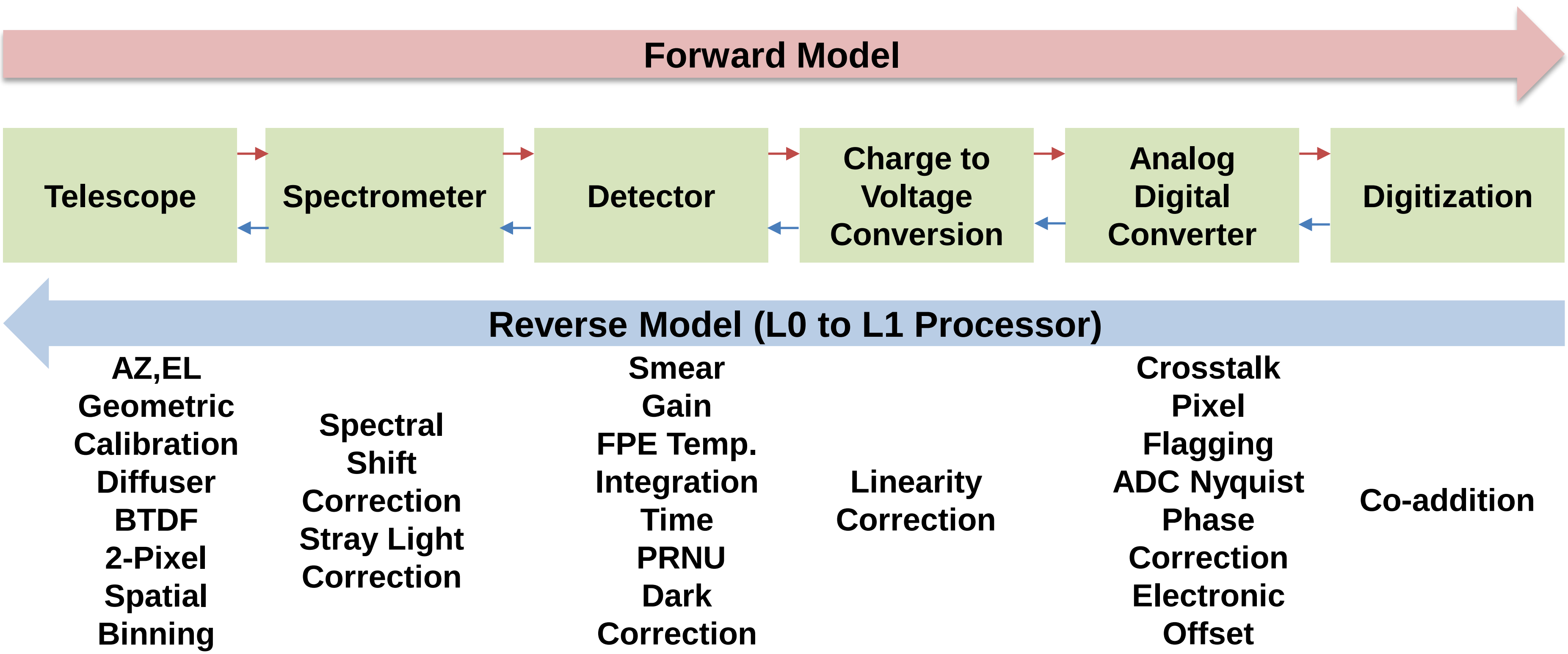
- GEMS L0-L1b processor
- Spectral calibration
- Stray light correction (poster)
- Summary and discussion

L0-L1b Processor

- All sub algorithms has been prepared (KARI)
  - Many of algorithms are comparable with TROPOMI/TEMPO.
  - No forward model is provided
    - End to end performance test is limited.
  - Several algorithms require improvement and optimization.

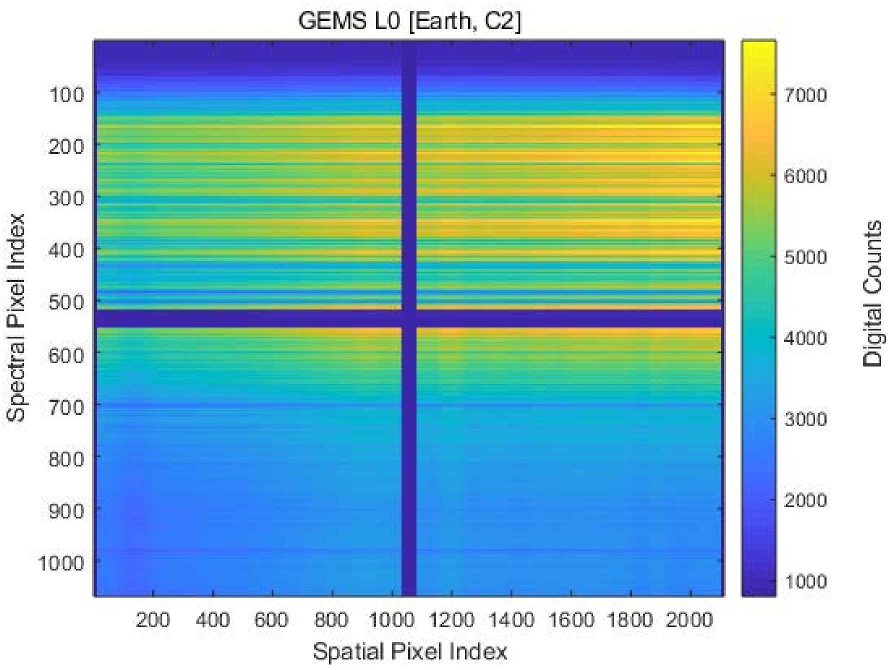
L0-L1b Processor

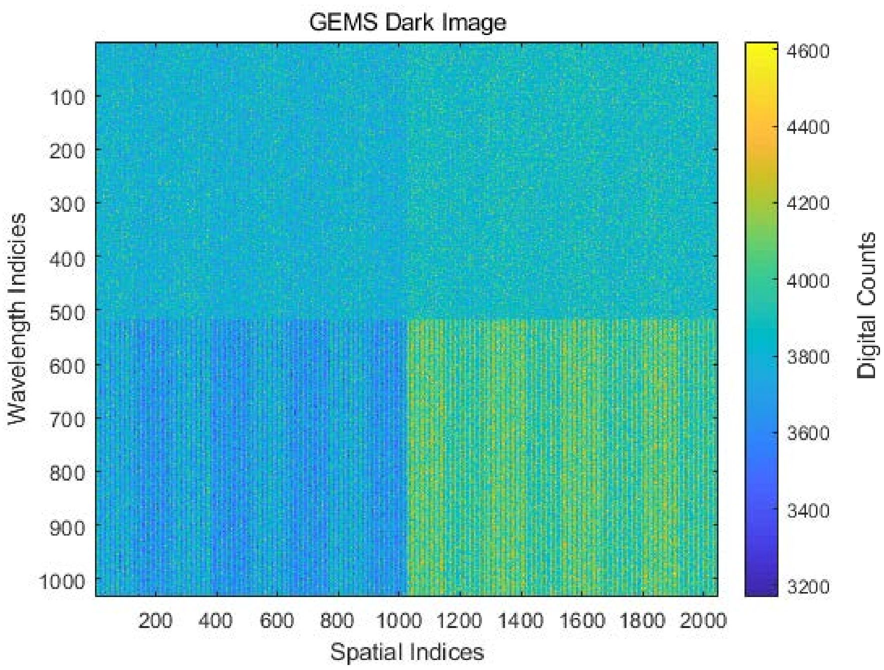
◆Signal chain of GEMS



L0-L1b Processor

- L0 to L1b data
  - GEMS simulated earth and dark image after co-addition correction

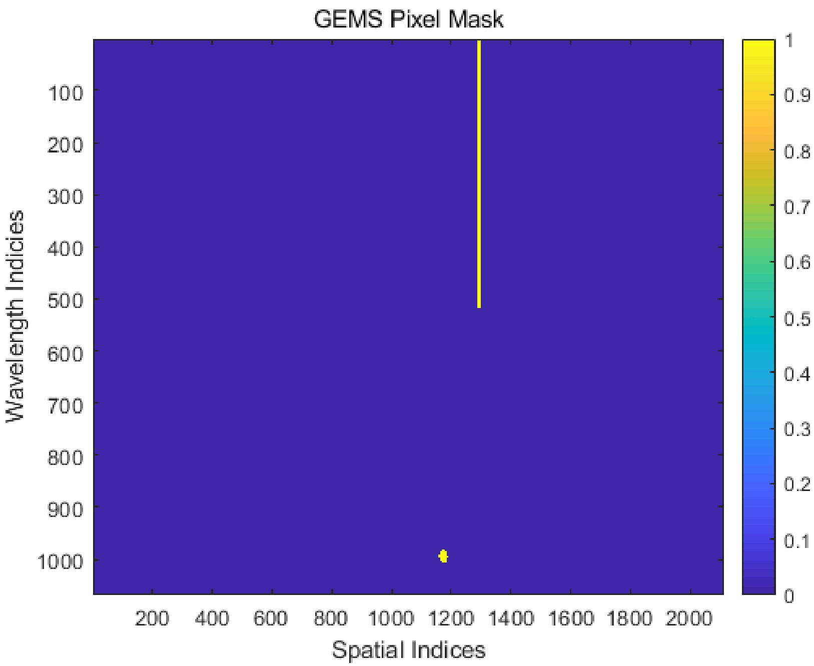


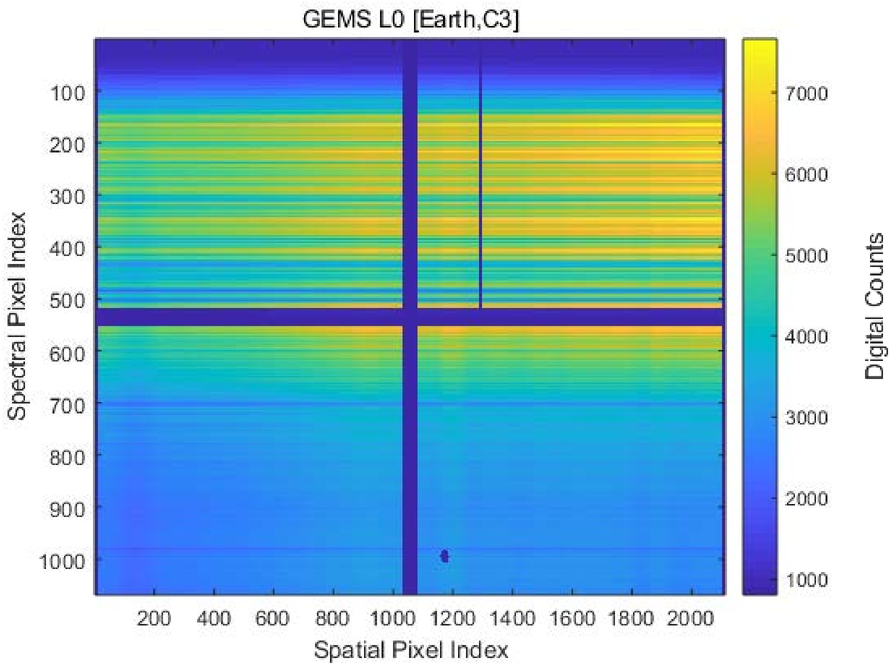


Wavelength indices 0 to 1032 (501.52 to 297.35 nm)
Spatial indices 0 to 2047 (north to south)

L0-L1b Processor

- L0 to L1b data
  - Apply pixel mask (dead pixel)



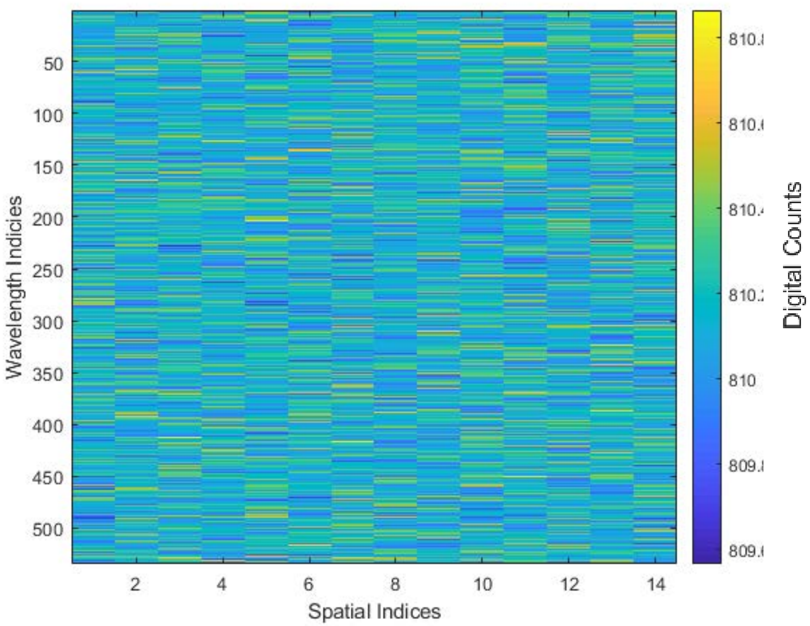


Wavelength indices 0 to 1032 (501.52 to 297.35 nm)
Spatial indices 0 to 2047 (north to south)

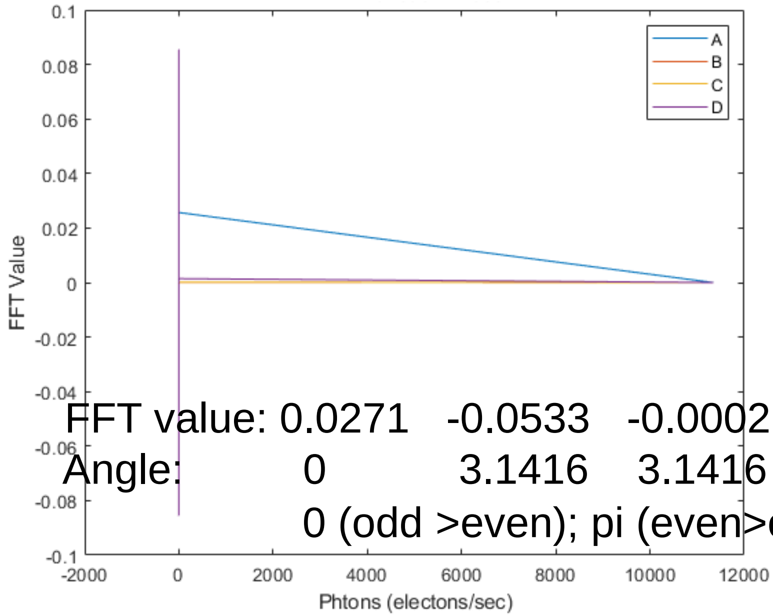
L0-L1b Processor

- L0 to L1b data
  - Determine Nyquist phase
    - Each of the four ADCs employ dual-path analog preamps, odd/even indexed pixels can take path 1 or 2

GEMS trailing overclock pixel



FFT value for Quadrant Image



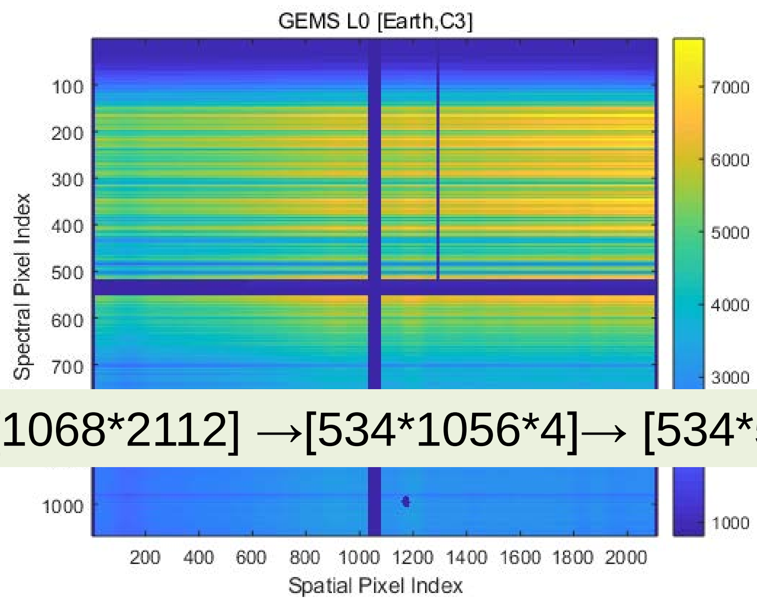
FFT value: 0.0271 -0.0533 -0.0002 0.0401

Angle: 0 3.1416 3.1416 0

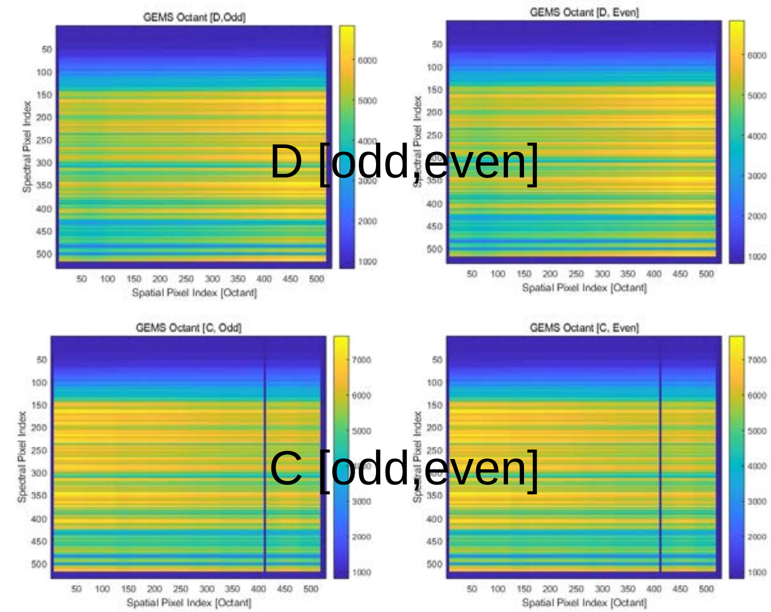
0 (odd >even); pi (even>odd)

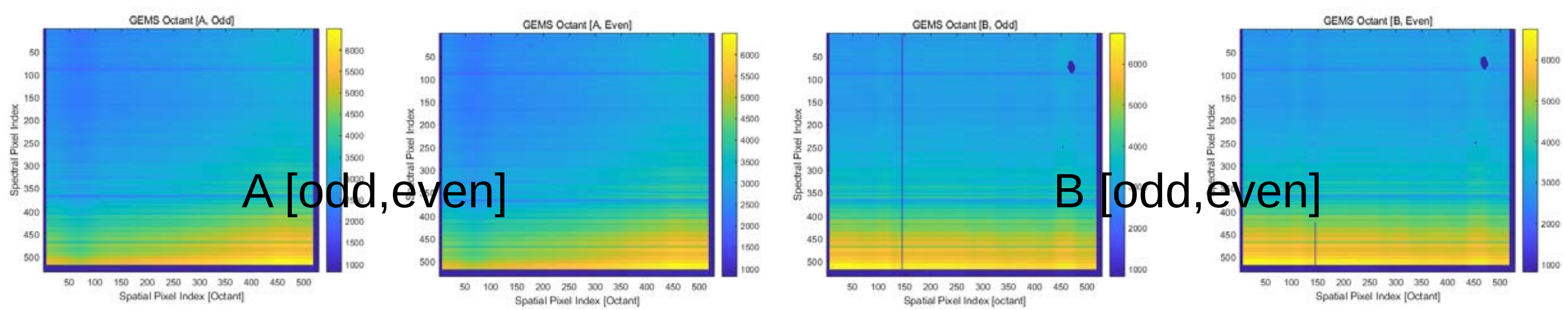
L0-L1b Processor

- L0 to L1b data
  - Quadrant/octant image



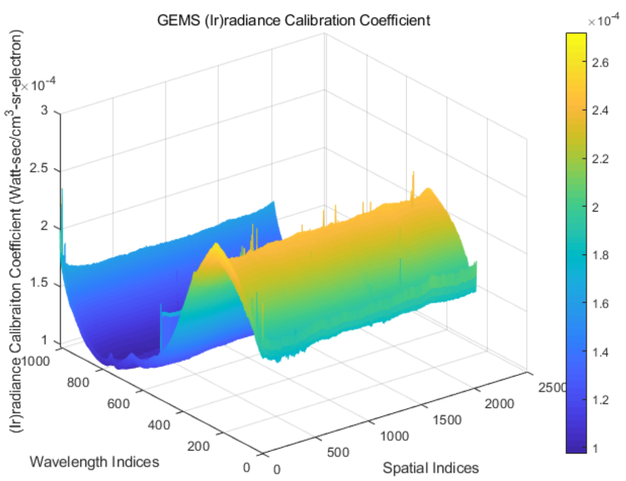
[1068*2112] →[534*1056*4]→ [534*528*8]



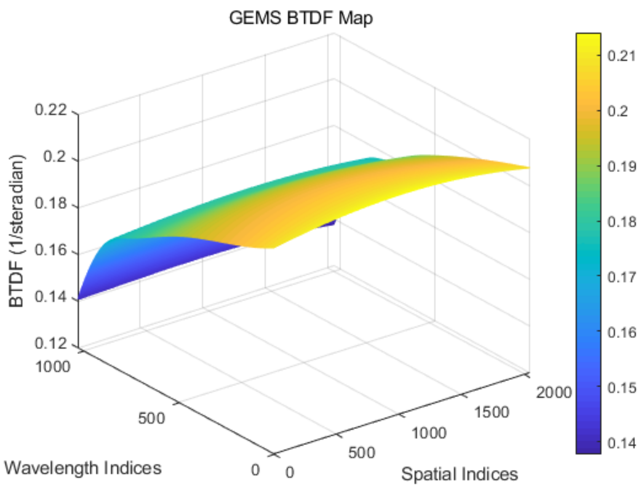


L0-L1b Processor

- Asses the calibration tables
  - BTDF, (Ir)radiance calibration coefficient as function of viewing angle
    - PRNU/slit irregularity/radiometric response wavelength dependence (including spectral feature), viewing angle dependence



Wavelength indices 10 to 1020 (499.75 to 299.93 nm)
Spatial indices 10 to 2030 (north to south)



Wavelength indices 0 to 1032 (501.52 to 297.35 nm)
Spatial indices 0 to 2047 (north to south)

Spectral Calibration

◆Comparison of algorithm (BATC vs. GEMS Team)

	BATC Algorithm	GEMS Algorithm
Minimization	Difference btw gradient of on-ground calibration data and of measurement	Difference btw reference spectrum and measurement
Method	Simplex method	OE (Optimal Estimation) Levenberg-Marqurdt
Fitting window	Single	Single or multiple
Calibration parameter	Shift	Selectable (Shift, Squeeze Shift Polynomial Shift with mini windows)
Data to be calibrated	**Spatially averaged measurement**	Individual observation data
SRF Characterization	**Not included**	Included

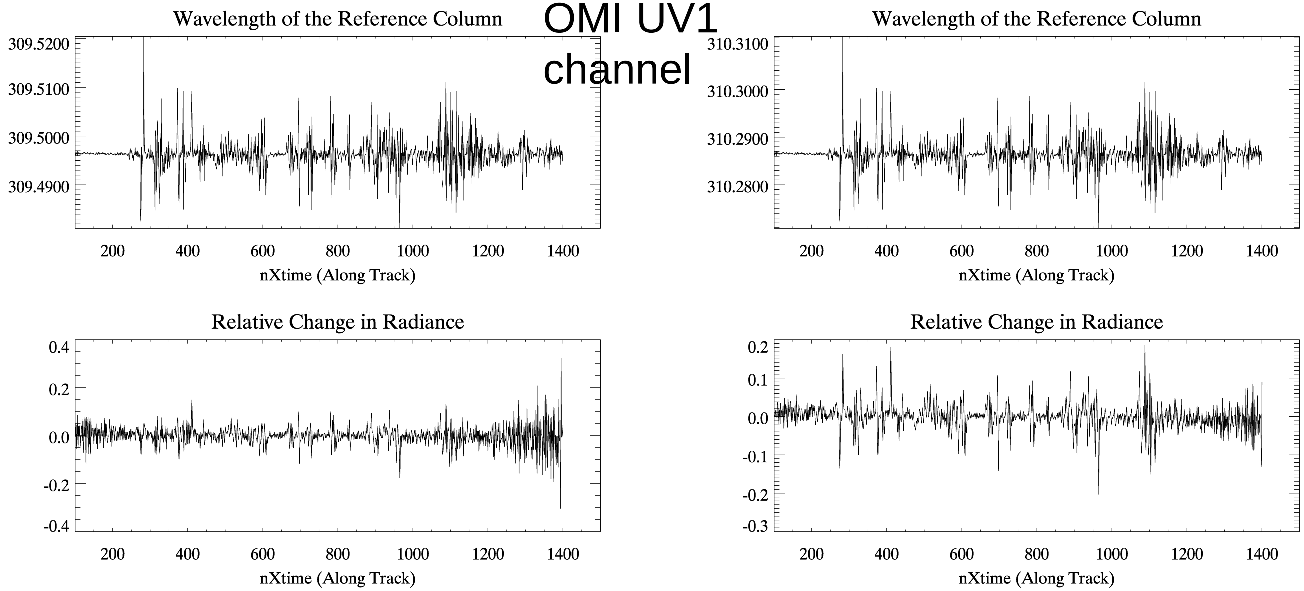
Spectral Calibration

GEMS algorithm

- Calibration for GEMS irradiance
  - Spectral fitting
    - in selected (mini) windows, polynomial fitting to the derived shifts for the whole channel
    - or fitting a polynomial shift for the entire range
- Calibration for GEMS radiance
  - Spectral assignment
    - Correct the shift from parametrization of the dependence on temperature and **scene inhomogeneity** (Voors et al., 2006)

Spectral Calibration

- Scene inhomogeneity impact on wavelength shift
  - Derived OMI wavelength shift shows significant consistency with relative change of radiance above 310 nm (Voors et al., 2006)



OMI UV1 channel

OMI UV2 channel

R; 0.87

ΔR=[Rad(i+1)-Rad(i-1)]/[Rad(i+1)+Rad(i-1)]

Spectral Calibration

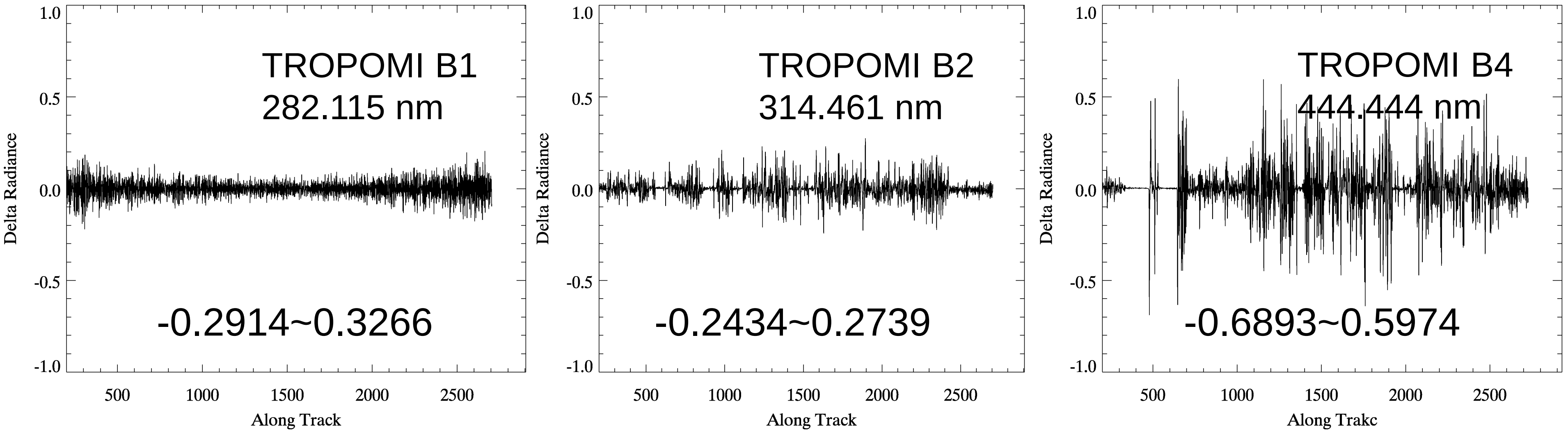
- Scene inhomogeneity impact on wavelength shift

Inhomogeneous illumination of the spectrometer's entrance slit (mainly by clouds) → Changes the shape and positon of the SRF → Wavelength shift

- important issue in hyperspectral Earth observation spectrometers with considerable resolution and field-of-view size.
  - **Less averaging effect** as it is not smoothing more than continuous scan (OMI, TROPOMI), **the effects might be serious** in stop and stare scanning mode **(GEMS/ TEMPO)**

Spectral Calibration

- Scene inhomogeneity impact on wavelength shift
  - To check the relationship btw relative change of radiance and wavelength shift, we use **TROPOMI radiance** and **GEMS spectral calibration algorithm**



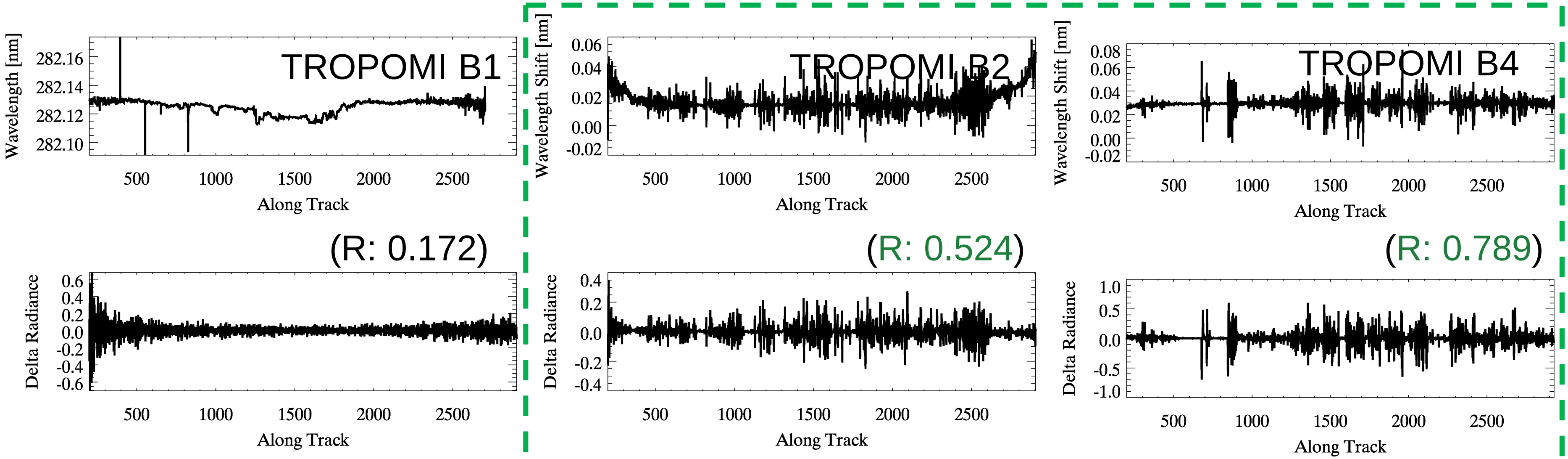
$\Delta R = [Rad(i+1) - Rad(i-1)]/[Rad(i+1) + Rad(i-1)]$

Spectral Calibration

◆Scene inhomogeneity impact on wavelength shift

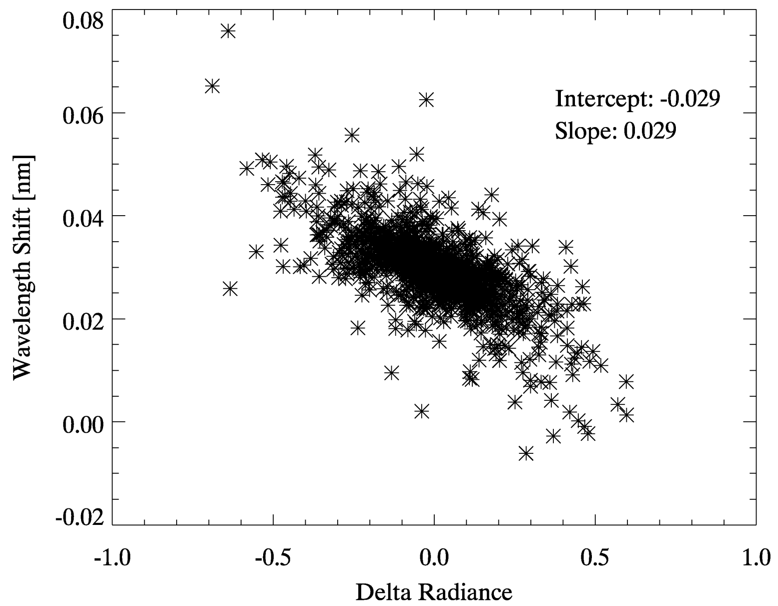
❖Conduct the spectral fitting to TROPOMI radiance

❖Compare the obtained wavelength shift with the relative change of radiance (delta radiance)



Spectral Calibration

- Scene inhomogeneity impact on wavelength shift
  - Changes in the **wavelength scale correlate** with changes in the observed **ground scene radiances**.
    - **Wavelength shift** in radiance **can be parametrized**
      - Delta lambda = conversion factor * delta radiance



Spectral Calibration

- IOT commissioning plan
  - Select the proper fitting parameters/option
    - shift/squeeze, shift with mini windows, shift polynomial
  - SRF monitoring
    - spectral resolution shall be verified early in the mission
  - Examine the relationship btw temperature gradient of optical bench/scene inhomogeneity and wavelength variations (shift) from spectral fitting
  - Verification of GEMS solar irradiance
    - Inter comparison with solar spectra measured by other satellite instrument
    - Trend monitoring

Spectral Calibration

GEMS algorithm

- Operational strategy
  - Solar irradiance
    - **Spectral calibration**
      - Fitting to correct the wavelength shift
    - Investigations on SRF changes
      - the shape, asymmetry and the SRF functional description fitted offline (not in the operational L0-1b data processor) to obtain the **most accurate** spectral calibration results.
  - Earth radiance
    - **Spectral assignment**
      - a fixed spectral grid assigning a wavelength to each detector pixel (**spectral registration**), and then corrected for shifts due to **scene inhomogeneity and thermal changes**

Stray Light Correction

◆Comparison of algorithm (BATC vs. GEMS Team)

	BATC Algorithm	GEMS Algorithm
Method	Estimate stray light using ratio with nominal scene stray light	Matrix multiplication based on PSF data
Dimension	Spectral only	Spectral and spatial
LUT	Fractional stray light from nominal scene Local index Ratio between the local mean signal of nominal scene and entire signal mean	Stray light Distribution Function Matrix (SDF)
Ground measured data for correction	**Point Spread Function** **Broad-band stray light measurement** for stray light model	**Point Spread Function** for SDF (Broad-band stray light measurement for stray light correction over 500 nm)

Stray Light Correction

- Out Of Band (OOB) stray light correction (BATC)
  - **OOB** is defined as **not intended light** from a source internal to sensor optical system
  - Estimate stray light of input spectrum using fractional stray light of nominal spectrum scaled by ratio between nominal and input spectrum

$$Q'_{sl}(i,j) = \frac{Q_{\frac{Nominal\ local}{global}}(i,j)}{Q_{\frac{input\ local}{global}}(i,j)} * SL_{nominal}(i,j) * Q'_{input}(i,j)$$

$$Q'_{corrected}(i,j) = Q'_{input}(i,j) - Q'_{sl}(i,j)$$

Q'_{sl} : Electron from stray light of input spectrum Q'_{input} : Electron from input spectrum

$SL_{nominal}$: Fractional stray light for GEMS nominal scene computed by correlated stray light model

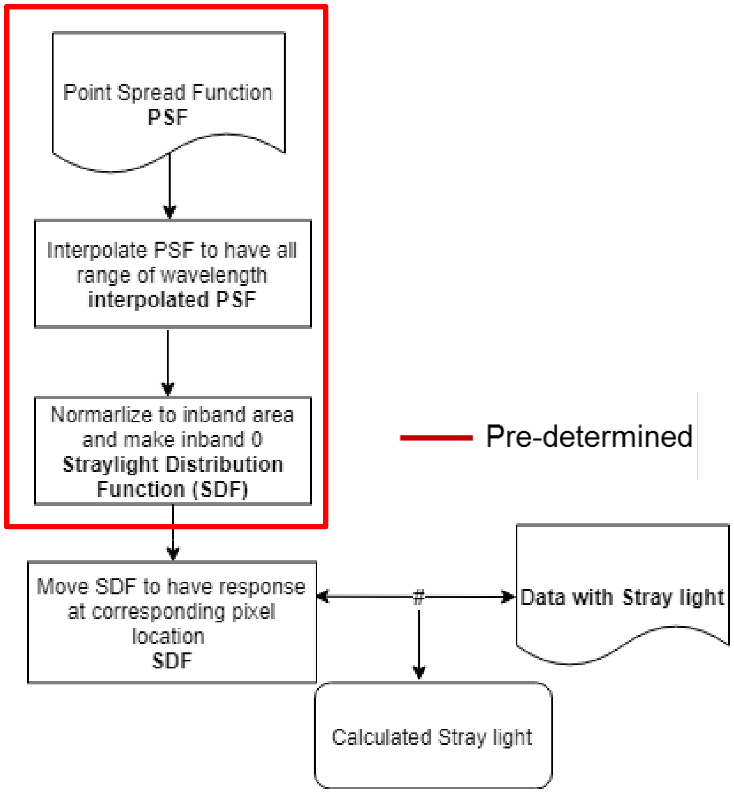
$Q_{\frac{local}{global}}$: Ratio between the mean signal along local segments of Input (nominal) scene to entire signal mean

Stray Light Correction

- Stray light correction based on PSF
  - Based on Stray light Distribution Function (SDF) matrix multiplication (Zong et al., 2007) (Feinholz et al., 2012)

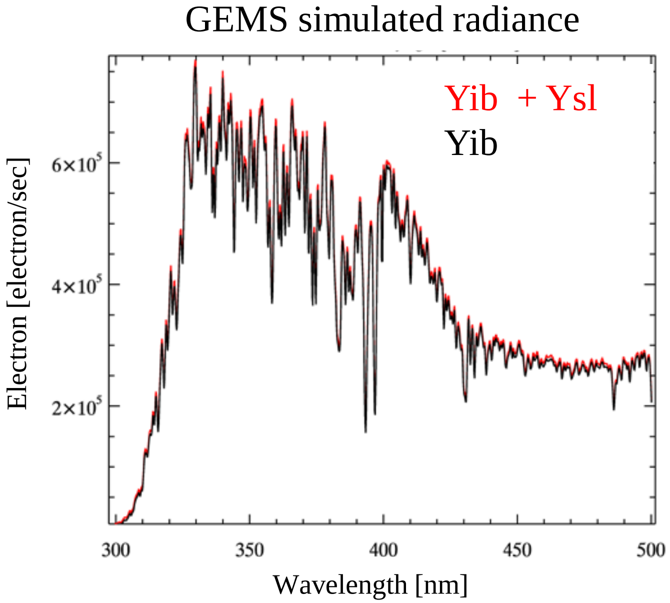
$$
\begin{aligned}
Y_{meas} &= Y_{inband} + Y_{SL} \\
&= Y_{inband} + D \cdot Y_{inband} \\
&= [I + D] \cdot Y_{inband} \\
&= A \cdot Y_{inband}
\end{aligned}
$$

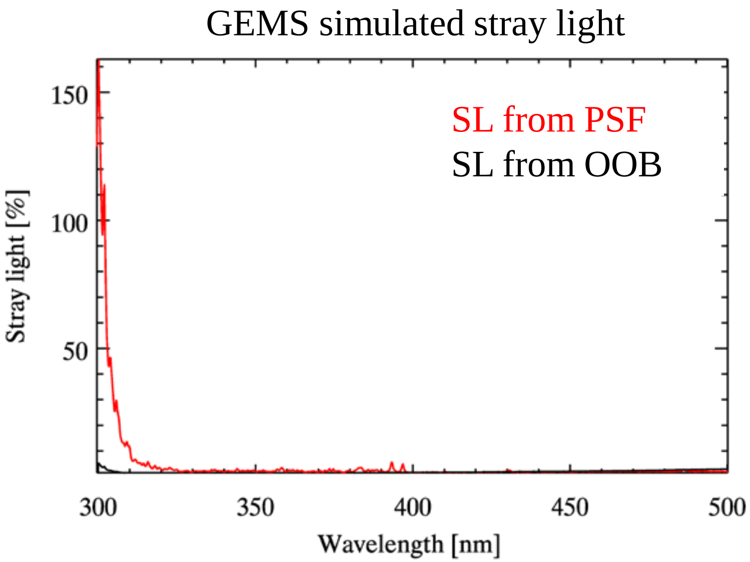
$$
\begin{aligned}
Y_{inband} &= A^{-1} \cdot Y_{meas} \\
&= C \cdot Y_{meas}
\end{aligned}
$$



Stray Light Correction

- Comparison of simulated stray light from each algorithm for GEMS irradiance
  - Input : Simulated GEMS radiance [Elections/sec]
  - Simulated stray light at 300 nm exists about 150 % with PSF while exists only 6 % with OOB





$$SL\ [\%] = \frac{Y_{sl}}{Y_{ib}} * 100$$

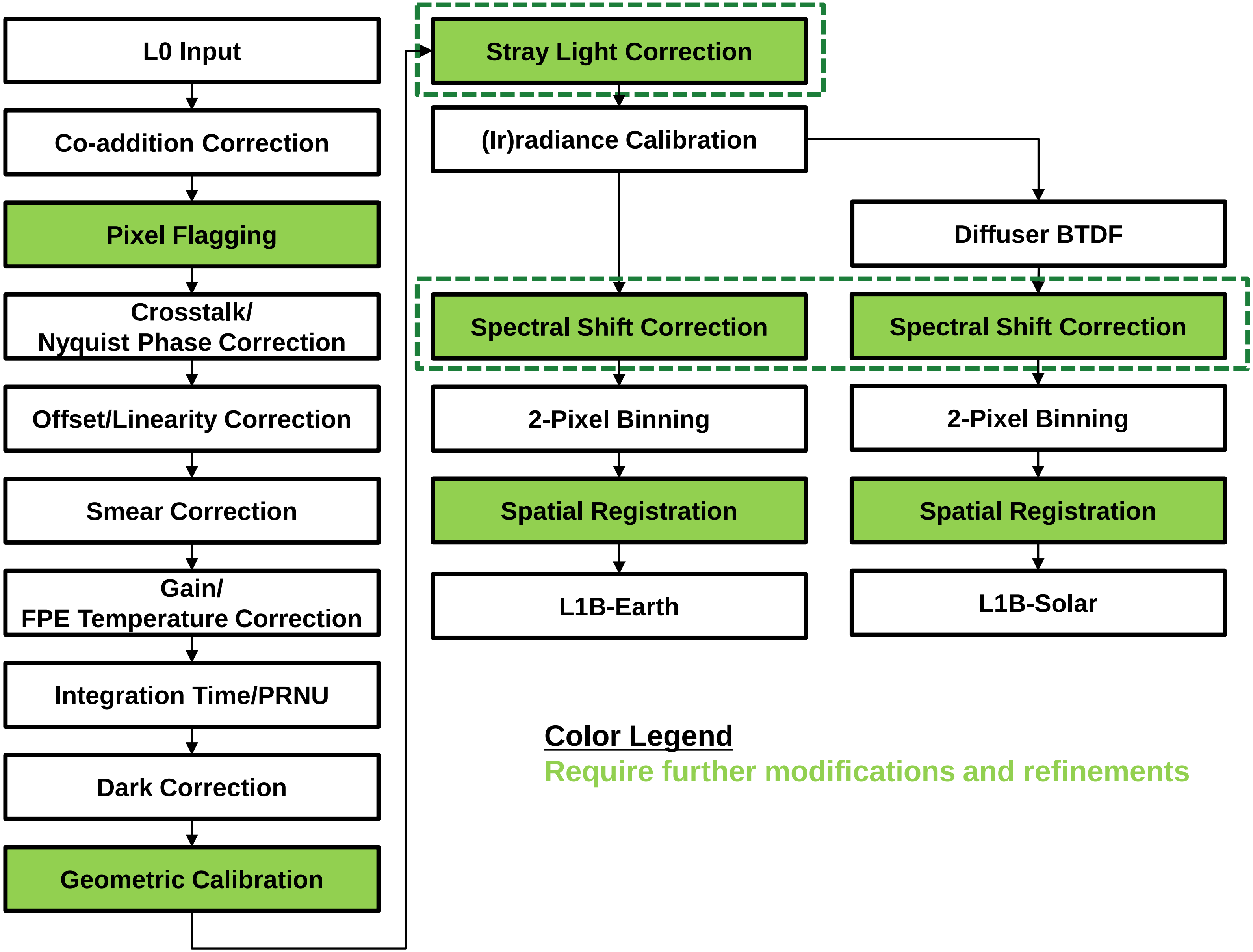
Y_{ib} : Input radiance
Y_{SL} : Simualted stray light

Summary and Discussion

- Detailed investigation and improvements of L0 to L1b processor with calibration tables are in progress.
- IOT plan and operational strategy for spectral calibration have been prepared.
- In-flight SRF, and wavelength shift will be monitoring to verify and check the prelaunch characterization and on-orbit performance.

Thank you

L0-L1b Processor

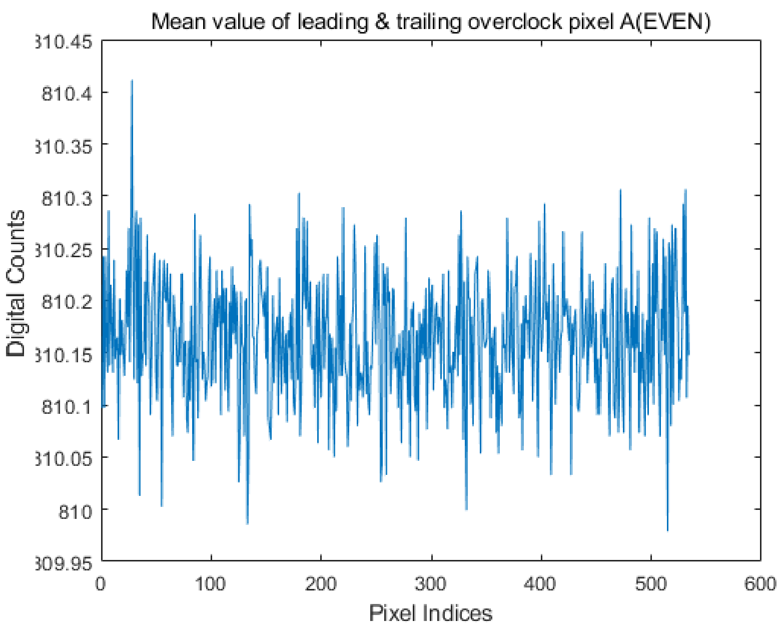


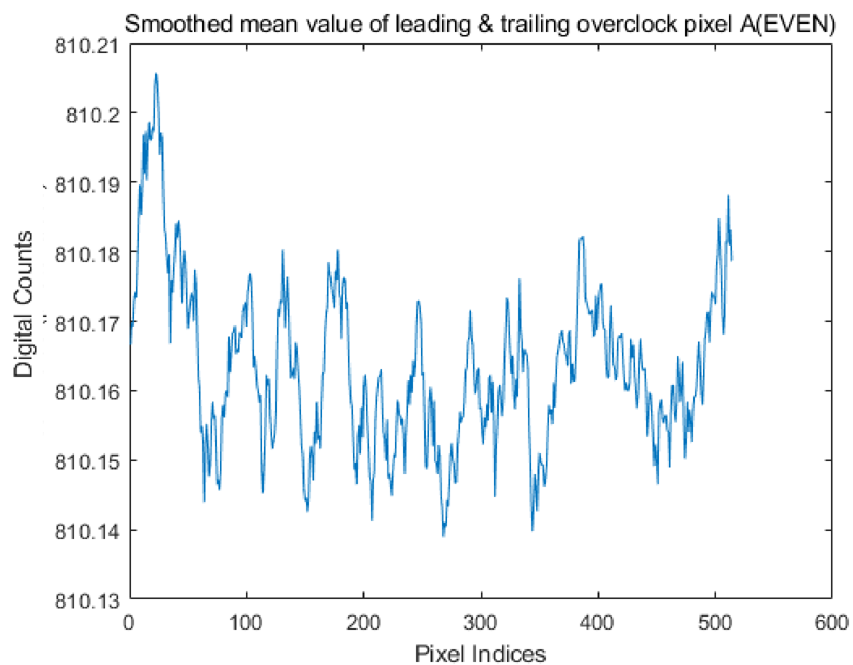
Color Legend

Require further modifications and refinements

L0-L1b Processor

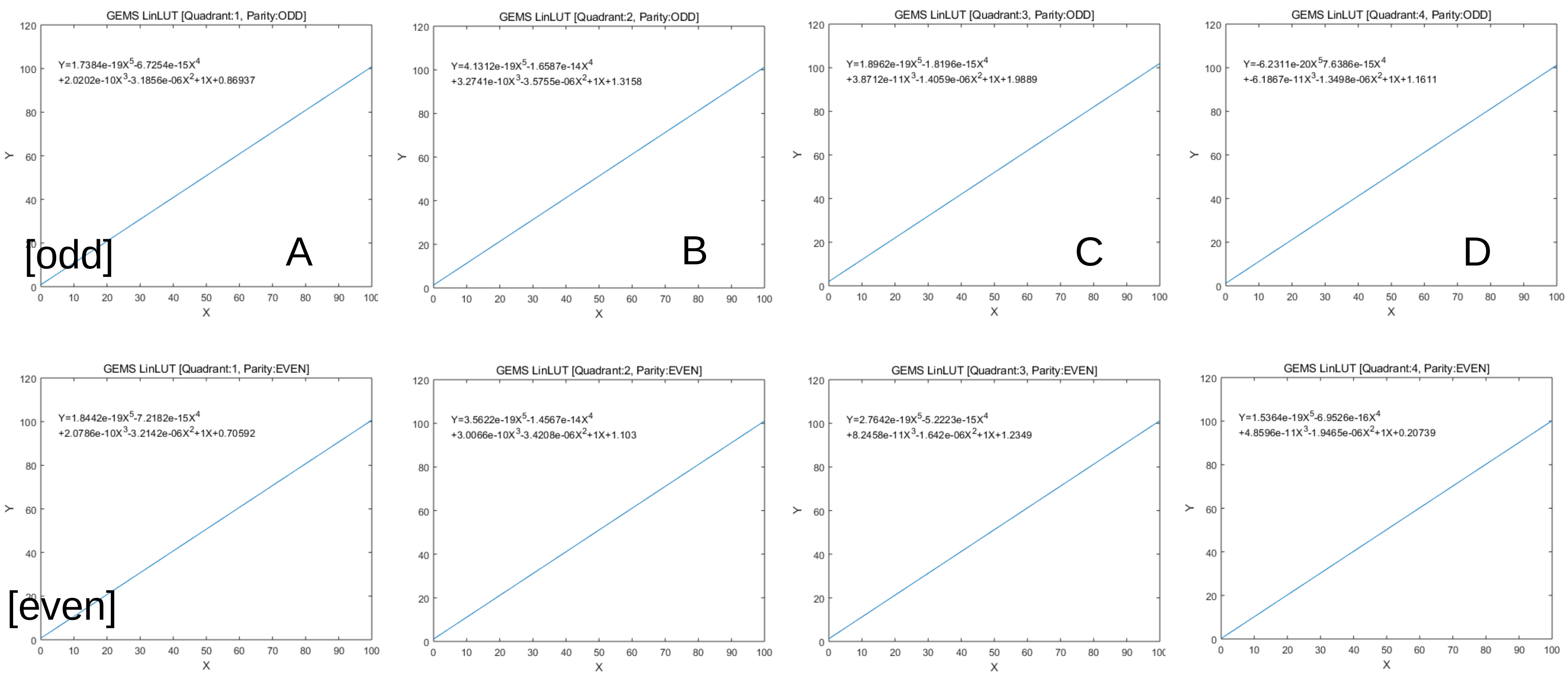
- L0 to L1b data
  - Electronic offset correction
    - Determined by computing the **mean signal contained within select leading and trailing serial overclock pixels** the result of which is convolved with a smoothing kernel to remove noise artifacts.





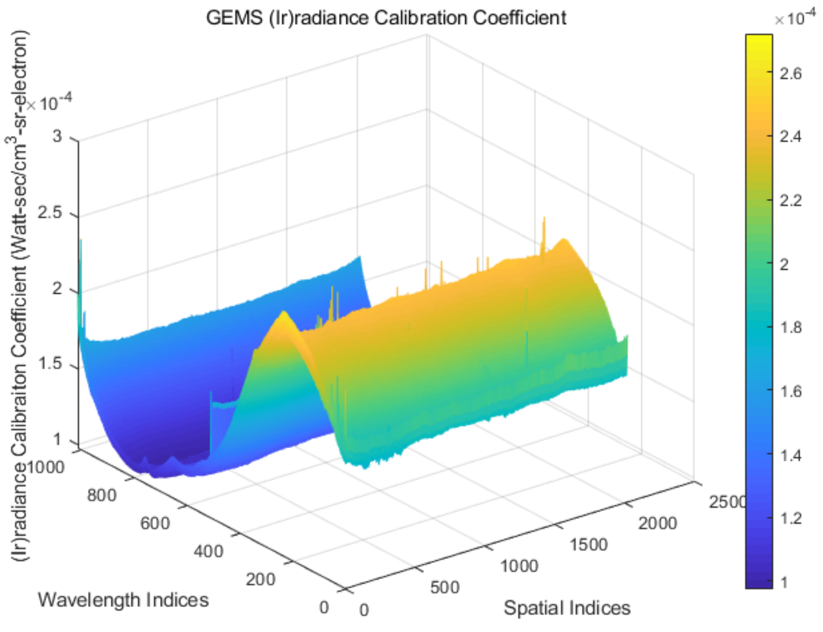
L0-L1b Processor

- L0 to L1b data
  - Linearity correction

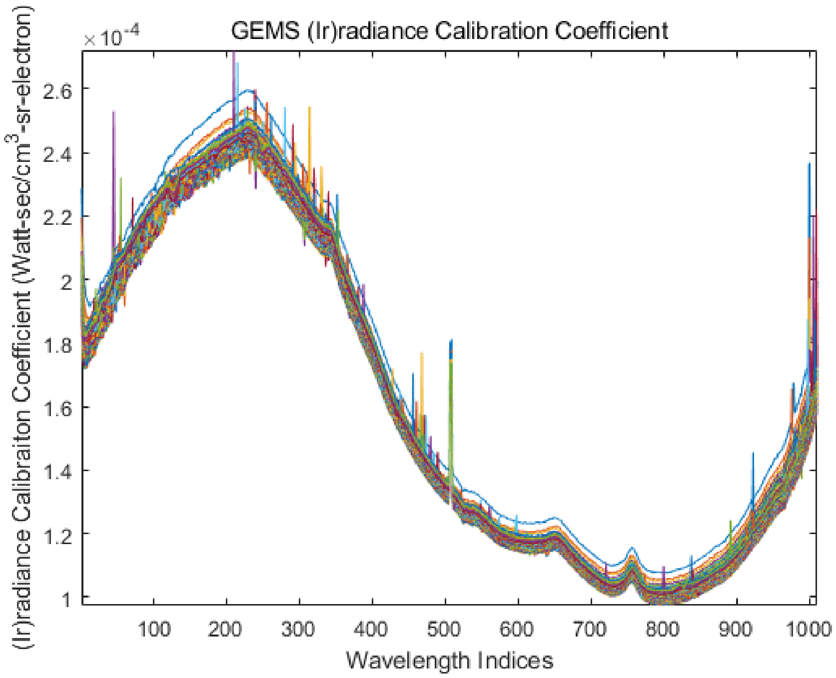


L0-L1b Processor

- Calibration table
  - Radiometric calibration coefficient
    - Further investigation is in progress



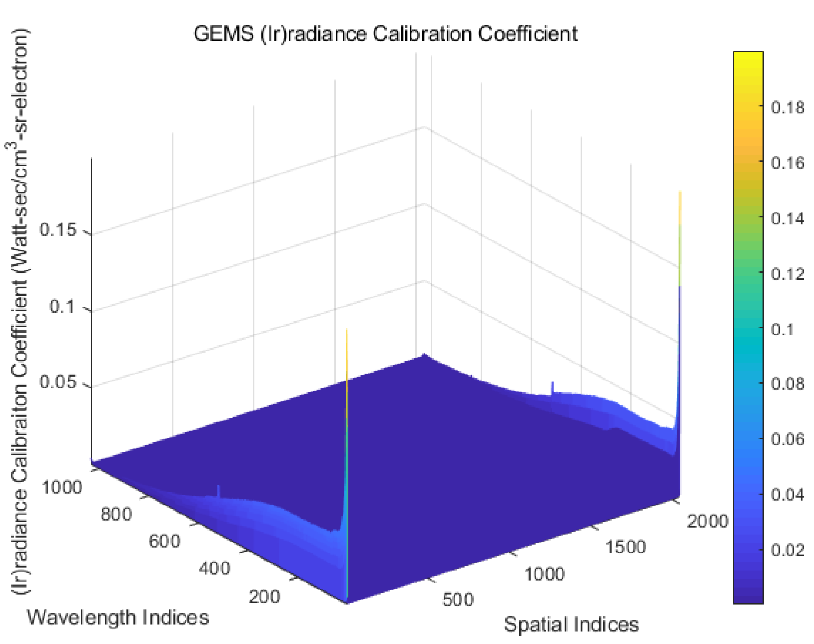
Wavelength indices 10 to 1020 (499.75 to 299.93 nm)
Spatial indices 10 to 2030 (north to south)

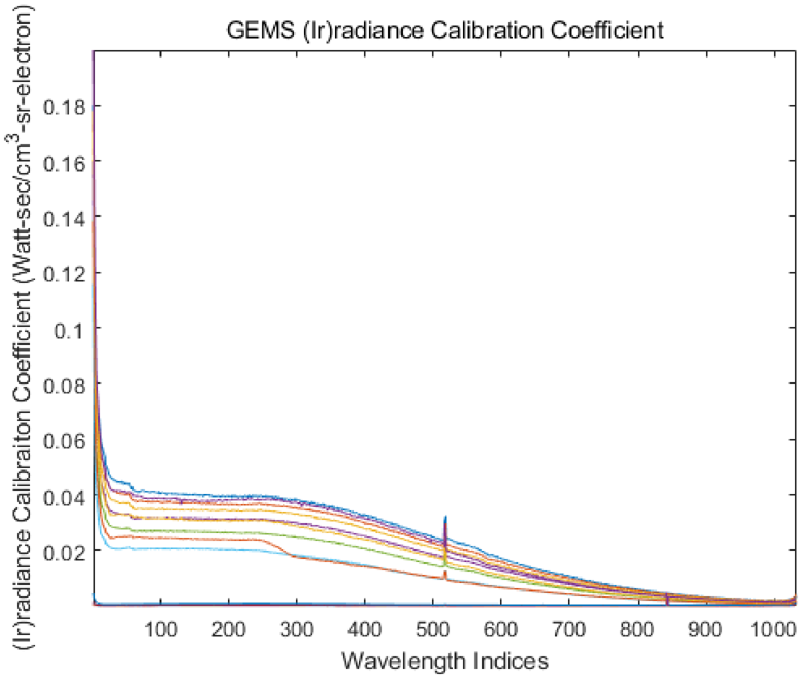


Spectral (10:1020), Spatial (10:2030)

L0-L1b Processor

- Calibration table
  - Radiometric calibration coefficient

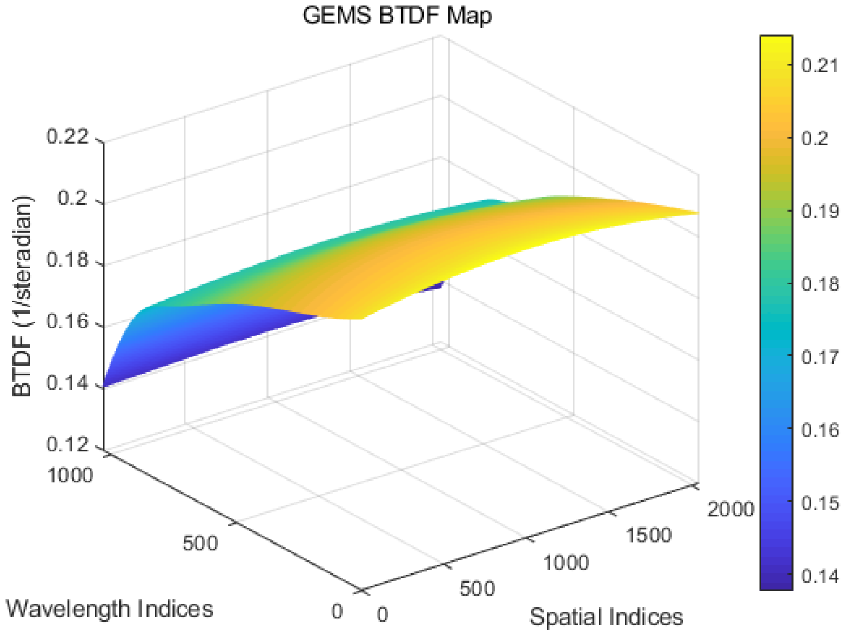


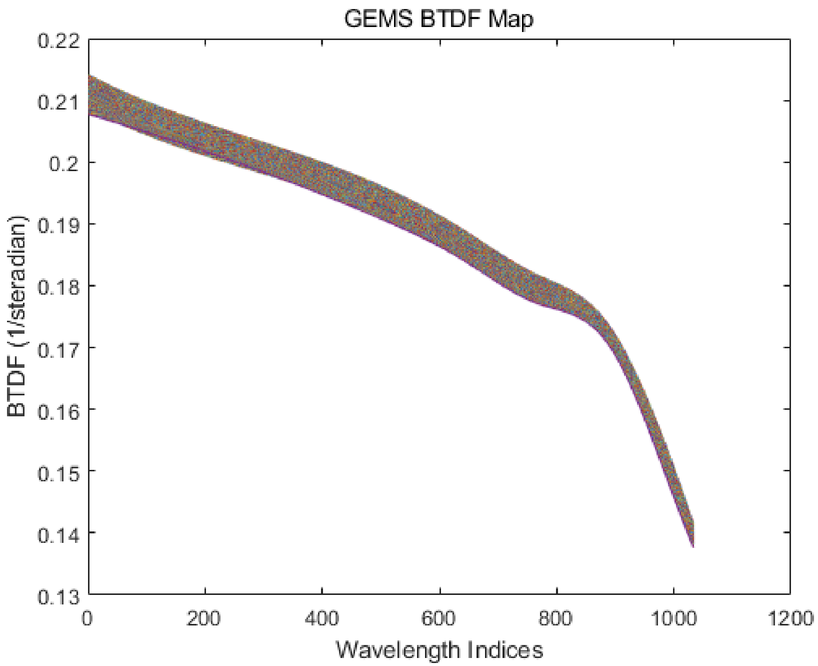


Wavelength indices 0 to 1032 (501.52 to 297.35 nm)
Spatial indices 0 to 2047 (north to south)

L0-L1b Processor

- **Calibration table**
  - **Diffuser BTDF**
    - diffuser BTDF is measured in both the spatial and spectral dimensions for various geometries



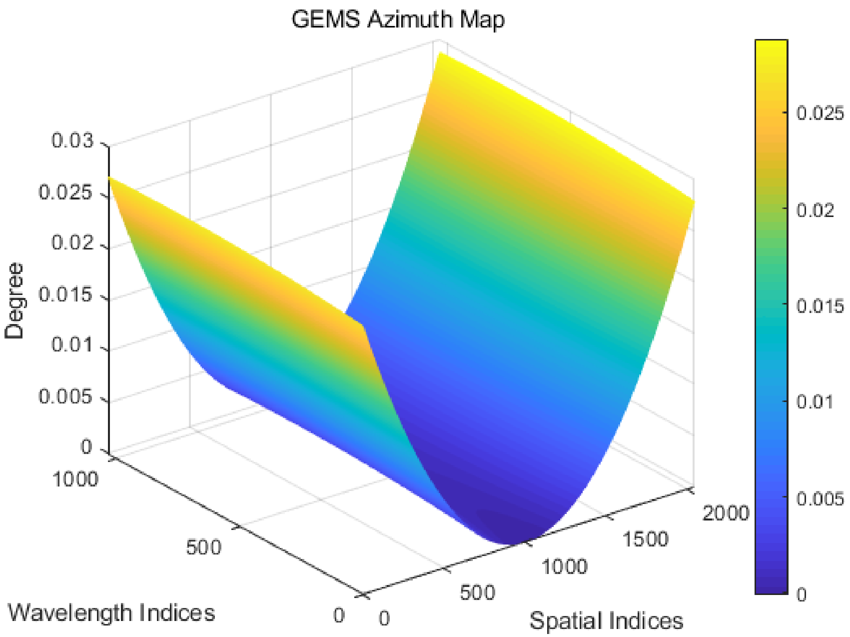


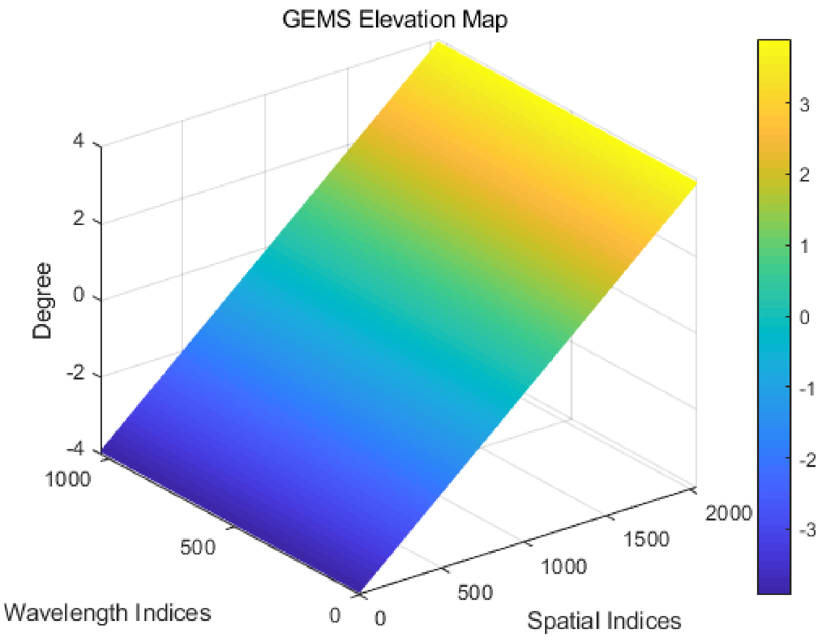
Wavelength indices 0 to 1032 (501.52 to 297.35 nm)
Spatial indices 0 to 2047 (north to south)

500 nm 3 00 nm

L0-L1b Processor

- Calibration table
  - GEMS AZ, EL map





L0-L1b Processor

Correction Algorithm	Current	Goal
Pixel flagging	Correct saturation/dead pixel	Saturation pixel Dead pixel Transient pixel (RTS)
Spectral shift correction	Based on the on-ground calibration data (0.2nm) No fitting window Aggregated along spatial direction Minimizing derivatives	Based on the reference solar data (0.01nm) Fitting windows Fitting along the every spatial direction Derivatives or integration
Spatial registration	Azimuth / Elevation angle of each pixels	Latitude / Longitude of each pixels
Stray light correction	Estimate spectral stray light using ratio with nominal scene stray light	Spectral and spatial correction based on PSF data and broad-band data

Spectral Calibration

Spatial Resolution Comparisons

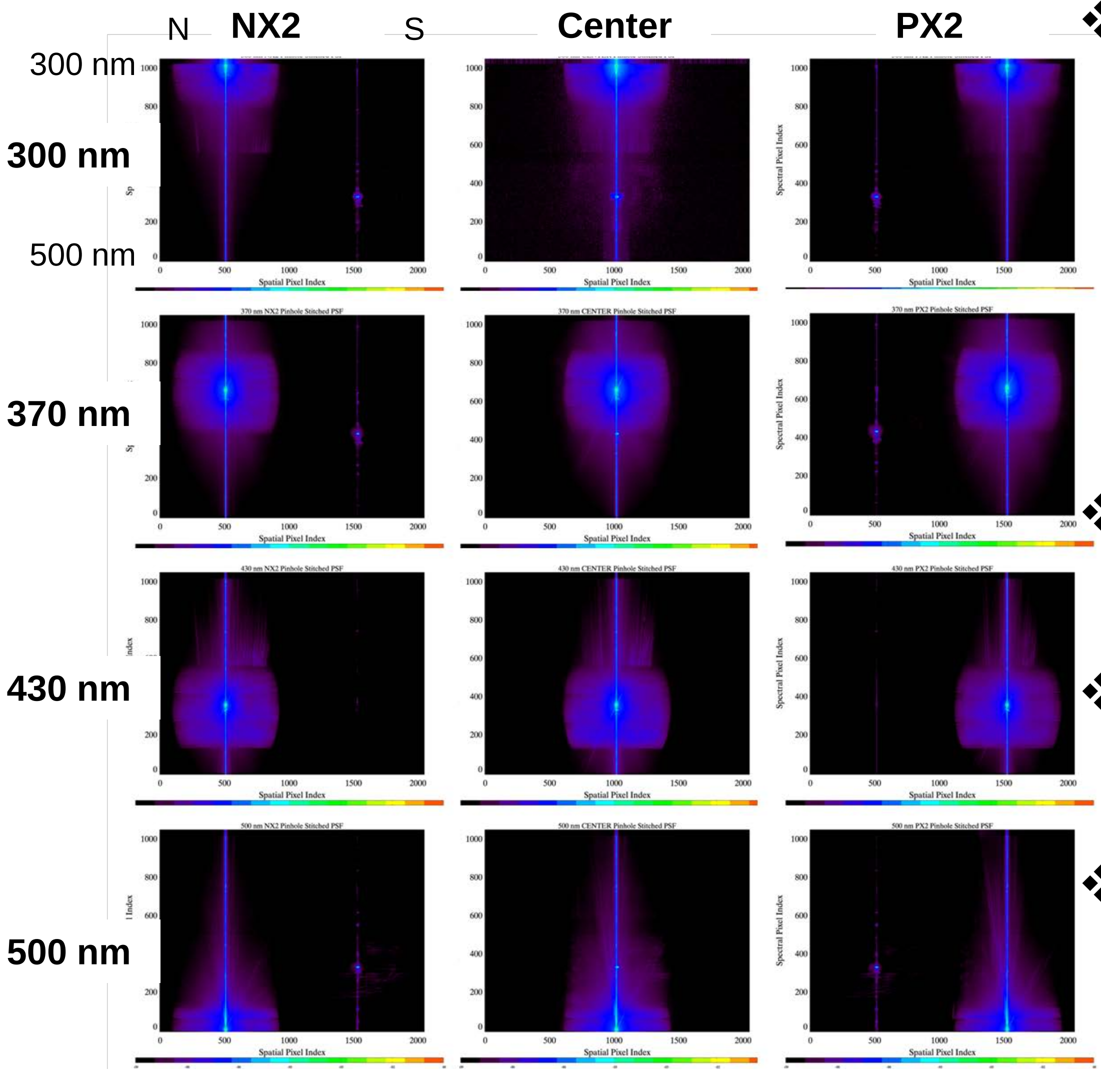
GOME: 40 x 40 km to 40 x 320 km
SCIAMACHY: 32 x 215
GOME-2: 80 x 40 km
OMI: 13 x 24 km
GEMS: 7 x 7 km

Credit: Prof. Jhoon Kim

Stray Light Correction

- Point Spread Function (PSF)
  - Stray light was characterized at the flight spectrometer level of assembly with the GSE pinhole assembly in place and tunable laser
    - Wavelength (nm) : 300, 370, 430, 500
    - Pinhole : NX2 (Northern-most illuminated pinhole), Center, PX2 (Southern-most illuminated pinhole)
  - PSF images are collected with different integration times to get stitched PSF data which have a high dynamic range of 1e9

Stray Light Correction



- ❖ GEMS PSF at four discrete wavelengths and at three discrete location within the GEMS FOV(Field of view)
  - Pinhole : NX2, Center, PX2
  - Wavelength (nm) : 300, 370, 430, 500
- ❖ GEMS detector size
  - [1033(Spectral),2048(Spatial)]
- ❖ Spectral and Spatial Ghost at specific location
- ❖ Defines the 19(3 FWHM) * 19 pixel box centered on the PSF peak as inband area

Stray Light Correction

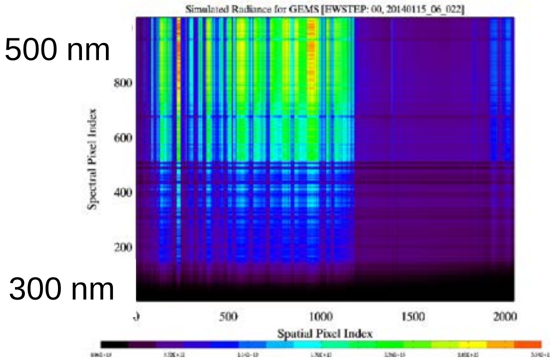
◆GEMS Point Spread Function (PSF)

❖ $SL = \frac{S_{outbnad}}{S_{inband}} * 100, \; inband = 1 + 3FWHM$

- Simulated GEMS radiance (20140115 06UTC)

Spatial Location	Stray light percent (Only from PSF)				
	300 nm	370 nm	430 nm	500 nm	MEAN
PX2 (1531)	1.89	1.83	1.95	1.79	1.865
Center (1021)	1.67	1.93	1.58	1.64	1.705
NX2 (512)	1.92	1.92	1.84	1.85	1.8825

Spatial Location	Stray light percent (PSF and simulated radiance)				
	300 nm (13)	370 nm (366)	430 nm (670)	500 nm (1024)	MEAN
PX2 (1531)	167	1.56	2.19	2.00	
Center (1021)	230	2.13	1.72	1.53	
NX2 (512)	337	1.84	1.97	1.52	



Stray Light Correction

- Stray light correction based on PSF
  - Stray light Distribution Function (SDF) matrix
    - To fully characterize an instrument's response for stray light, the relative stray light response (PSF) for every excitation pixel should be known
    - The Shape of PSF changes smoothly across the pixel with excitation element, so the other PSF can be obtained by interpolation
    - Devide PSF with total inband area and make inband area 0 to consider only outband area to calculate stray light with Stray light Distribution Function Matrix(D-matrix)

Stray Light Correction

- Stray light correction based on PSF
  - Stray light Distribution Function (SDF) matrix

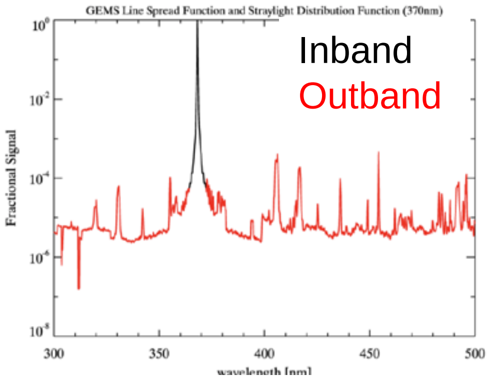


Figure. GEMS spectral Line Spread Function colored with outband area

$$D = \begin{bmatrix} d^{1,1} & d^{1,2} & \cdots & d^{1,m} \\ d^{2,1} & d^{2,2} & & d^{2,m} \\ \vdots & \vdots & \vdots & \vdots \\ d^{i,1} & d^{i,2} & d^{i,j} & d^{i,m} \\ \vdots & \vdots & \ddots & \vdots \\ d^{m-1,1} & d^{m-1,2} & \cdots & d^{m-1,m} \\ d^{m,1} & d^{m,2} & \cdots & d^{m,m} \end{bmatrix}$$

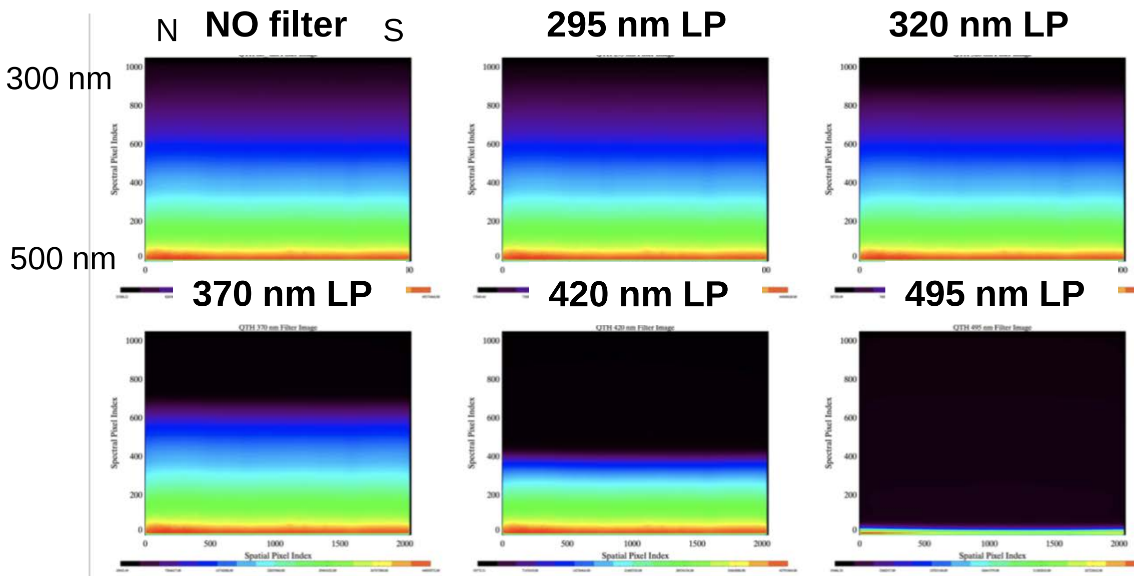
i : response element
j : excitation element

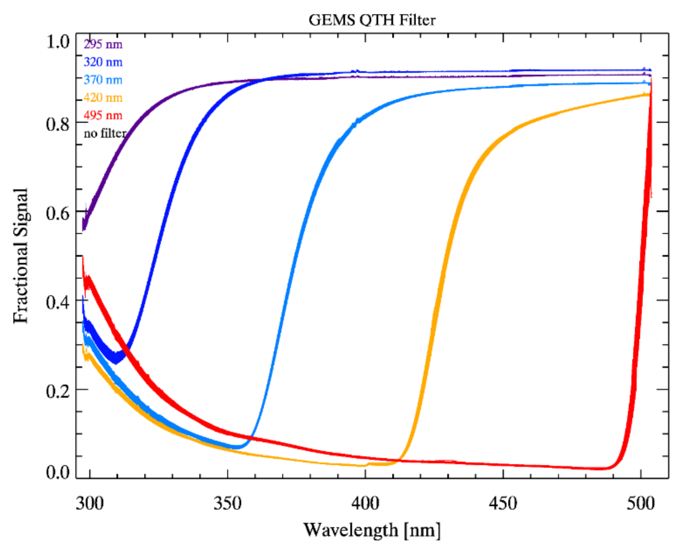
- $$D = \begin{bmatrix} \overleftrightarrow{D}^{1,1} & \overleftrightarrow{D}^{1,2} & \cdots & \overleftrightarrow{D}^{1,m} \\ \overleftrightarrow{D}^{2,1} & \overleftrightarrow{D}^{2,2} & \cdots & \overleftrightarrow{D}^{2,m} \\ \vdots & \vdots & \ddots & \vdots \\ \overleftrightarrow{D}^{m,1} & \overleftrightarrow{D}^{m,2} & \cdots & \overleftrightarrow{D}^{m,m} \end{bmatrix}, \quad \overleftrightarrow{D}^{1,1} = \begin{bmatrix} \overset{1,1}{d}{}^{1,1} & \overset{1,1}{d}{}^{1,2} & \cdots & \overset{1,1}{d}{}^{1,n} \\ \overset{1,1}{d}{}^{2,1} & \overset{1,1}{d}{}^{2,2} & \cdots & \overset{1,1}{d}{}^{2,n} \\ \vdots & \vdots & \ddots & \vdots \\ \overset{1,1}{d}{}^{n,1} & \overset{1,1}{d}{}^{n,2} & \cdots & \overset{1,1}{d}{}^{n,n} \end{bmatrix}$$

$\overset{k,l}{d}{}^{i,j}$, i : Spatial response element , j : Spatial excitation element
k : Spectral response element, l : Spectral excitation element
n : Spectral array number (1033), m : Spatial array number (2048)

Stray Light Correction

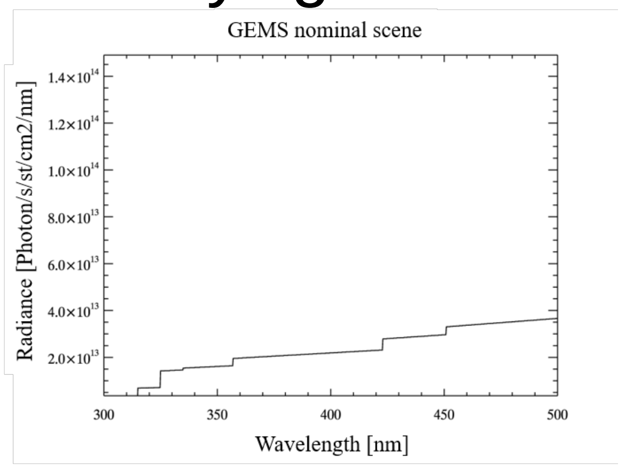
- GEMS broad-band stray light measurements
  - Broad-band stray light was measured by observing a diffuse QTH radiance source through a combination of short-pass and long-pass filters
    - Gathered by illuminating sensor with a broadband source at multiple field angles using multiple cutoff filter configuration.
      - [No filter, 295, 320, 370, 420, 495 nm]

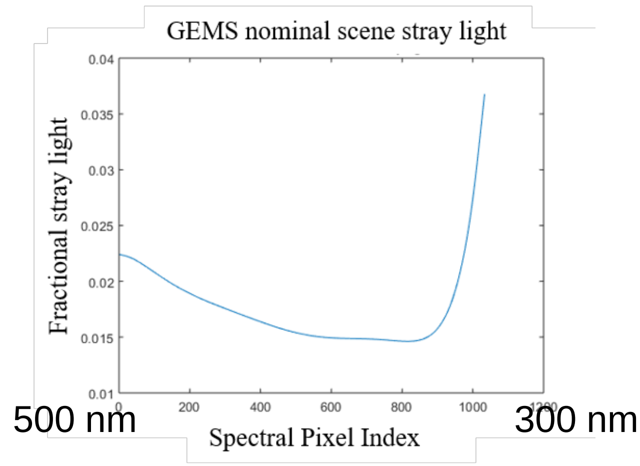




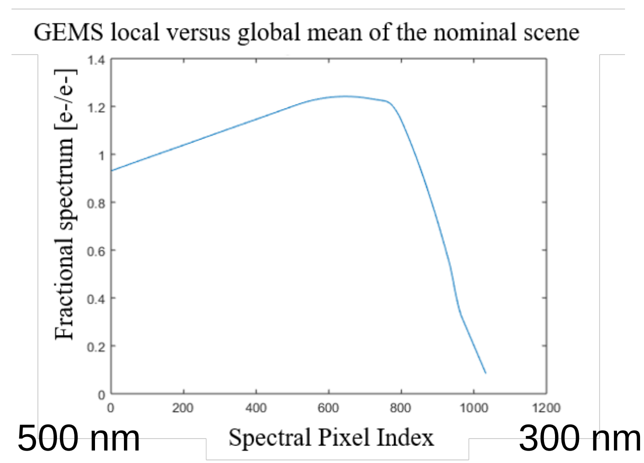
Stray Light Correction

- Out Of Band (OOB) stray light correction (BATC)
  - OOB stray light correction LUT





Local Index		Wavelength [nm]	
1	386	501.5199	425.3167
407	808	421.1653	341.8946
853	895	332.9921	324.6806
902	940	323.2950	315.7722
961	1021	311.6138	299.7278



Stray Light Correction

- Comparison of simulated stray light from each algorithm for GEMS irradiance
  - For OOB correction, simulated stray light depend on **fractional stray light of nominal scene** which is provided from BATC
    - Computed by sophisticated stray light model correlated against Point Spread Function (PSF) and broad-band stray light measurements